Turbulence Dynamics in Irregular Breaking Waves

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LONG-TERM GOALS

My long-term goals are to provide a detailed picture of the breaking and decay of irregular waves in a laboratory surf zone, and of the generation and evolution of the related turbulent flow fields.

OBJECTIVES

The scientific objectives of this project are:

1. To understand the effects of incident wave spectrum on the distributions of breaking wave characteristics and turbulent flow properties in the surf zone.

2. To determine the effect of offshore bar on the wave breaking process.

3. To elucidate the properties of breaking-induced vortex structures.

APPROACH

Carefully designed laboratory experiments are used to achieve the stated objectives. A new 25 m long, 0.9 m wide and 0.75 m deep precision tilting flume was commissioned at South Dakota State University in February 2002. This flume is equipped with a programmable random wave generator, with active wave absorption control to minimize wave reflection from the wave paddle. Laboratory experiments are carried out for different incident wave spectra developed from the JONSWAP spectrum by varying the spectral significant wave height, spectral peak period, spectra shape parameters, and beach slope. The experiments involve detailed measurement of the water surface elevations inside the surf zone using an array of capacitance wave gages, measurement of turbulent flow velocities in a vertical line in the outer, middle and inner surf zone using a three-component laser-Doppler anemometer (LDA), measurement of instantaneous three-dimensional velocity fields in a plane under the breaking waves using a stereoscopic particle image velocimetry (PIV) system, and videotape recording of the wave breaking process. The wave measurements are used to determine the characteristics of the breaking waves. The LDA measurements are used to determine the horizontal and vertical distributions of the undertow, radiation stresses and Reynolds stresses. The PIV measurements are used to determine the physical configuration, and the kinematical and dynamical properties of the breaking-induced vortices. The results are synthesized to provide a complete picture

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14. ABSTRACT

My long-term goals are to provide a detailed picture of the breaking and decay of irregular waves in a laboratory surf zone, and of the generation and evolution of the related turbulent flow fields.

15. SUBJECT TERMS

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of the surf zone flow field as a function of incident wave conditions. Similar measurements are planned for a barred beach.

WORK COMPLETED

We have analyzed the surf zone flow field on a 1 in 35 plane slope for a broad-band and a narrow-band irregular wave train (Ting, 2001, 2002). The preliminary experiments were conducted at Texas A&M University. Based on the results of those experiments, a detailed experimental investigation was planned and carried out in the new flume at South Dakota State University. In the new experiments, the water surface elevation was measured as a function of time at a large number of locations on a 1 in 50 plane slope. At each wave gage position, five wave time series conducted under the same experimental conditions were measured to compute an ensemble average. The ensemble-averaged wave elevations were used to determine the wave set-up, and the wave height, wave period, wave steepness, and horizontal and vertical asymmetry for the individual waves. Video recordings of the breaking waves were analyzed to determine the temporal and spatial distributions of wave breaking, the breaker types, and the area of the surface rollers. Some measurements with regular waves were also made for comparison purposes.

The horizontal and vertical distributions of the undertow, radiation stresses, and Reynolds stresses are being measured from the bottom to approximately the mean wave trough level with a three-component LDA. At each measuring point, the velocity measurements are repeated ten times with the same incident wave conditions in order to determine the wave-induced velocities and turbulence velocities by ensemble averaging. The surface mass flux is inferred from the measured undertow by numerically integrating the measured undertow from the bottom to the trough level. The eddy viscosity is determined from the measured undertow profile and Reynolds shear stress.

RESULTS

Figure 1(a) is a plot of the wave set-up/set-down throughout the wave tank for narrow-band and broad-band incident waves. The length of each wave record was 10 min. The spectral significant wave height and spectral peak period of the incident waves were 0.12 m and 1.8 s, respectively, at the wave paddle where the still water depth was 0.30 m. For both wave spectra, wave breaking on the 1 in 50 plane slope was dominated by spilling type breakers. A notable difference between the two incident wave conditions is that the narrow-band waves formed wave groups that were strongly modulated, whereas the broad-band waves were more or less random.

As shown in Figure 1(a), there is a decrease in the mean water level (set-down) in the offshore region and an increase in mean water level (set-up) near the shoreline. Because irregular waves break over a range of water depths, the increase in wave momentum flux in the shoaling waves is partially cancelled out by the decrease in wave momentum flux in the breaking waves. The result is a smaller maximum wave set-down and set-up compared to regular waves. Additionally, the point of maximum set-down is not as well defined as in regular waves. The variation of breaking wave fraction (Figure 1(c)) is similar for the narrow-band and broad-band waves. However, the narrow-band waves have a smaller set-down and a larger set-up compared to the broad-band waves. Flow observations show that the breaking of the narrow-band waves was closely correlated with the initial variation of wave heights within the wave groups. The waves with the larger initial heights broke first, followed by the smaller waves at the head and rear of the groups. The decrease in wave momentum flux due to the breaking of large waves may be the reason for the smaller set-down in the outer surf zone. This conclusion is

supported by the distributions of wave-height-to-water-depth ratio shown in Figure 1(b). This figure shows that the mean of the highest one-third values of the wave-height-to-water-depth ratio is larger for narrow-band waves than for broad-band waves in the outer surf zone. In the inner surf zone, however, the wave-height-to-water-depth ratio approaches the same constant value. Thus, the wave conditions in the inner surf zone are relatively insensitive to the shape of the incident wave spectrum.

In Figure 2 the measured undertow profile from the narrow-band waves is compared with that from a spilling regular wave. These measurements were taken in the inner surf zone where the wave-height-to-water-depth ratio approaches a constant value. The wave height and period of the regular waves are the same as the spectral significant wave height and spectral peak period of the irregular waves at wave generation. Figure 2 shows that the undertow profile from the irregular waves is more uniform and lower in magnitude compared to that from the regular spilling wave. These results indicate that the mean surface mass flux and turbulent shear at the trough level are smaller in the irregular waves. Work is currently underway to correlate the surface mass flux inferred from the undertow measurements and the measured turbulent shear at the trough level to the characteristics of the breaking waves.

IMPACT/APPLICATIONS

A successful outcome of this project would be a detailed picture of the breaking and decay of irregular waves in a laboratory surf zone, and of the generation and evolution of the related turbulent flow fields. The data collected in this project should be useful for testing a wide range of surf zone modeling techniques, including both present day models and models that are under long-range development.

TRANSITIONS

This project is complementary to related work in the National Oceanographic Partnership Program (NOPP) to develop a community model of nearshore waves, current and bathymetric change.

RELATED PROJECTS

1. NSF Grant Number CTS-0078926, “Acquisition of a Multi-Purpose Open-Channel Flume for Water Flow Studies,” Francis C. K. Ting et al., South Dakota State University. This equipment grant has provided partial funding for the new flume.

2. N00014-99-1-1051 (NOPP), “Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean,” James T. Kirby et al., University of Delaware. We are coordinating with Professor Kirby to maximize the ability that the experimental data may be used for parameterization and testing of numerical models.

REFERENCES

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PUBLICATIONS

Ting, F. C. K (2002), "Wave and turbulence characteristics in narrow-band irregular breaking waves," <u>Coastal Engineering</u>, Vol. 46, 291-313.

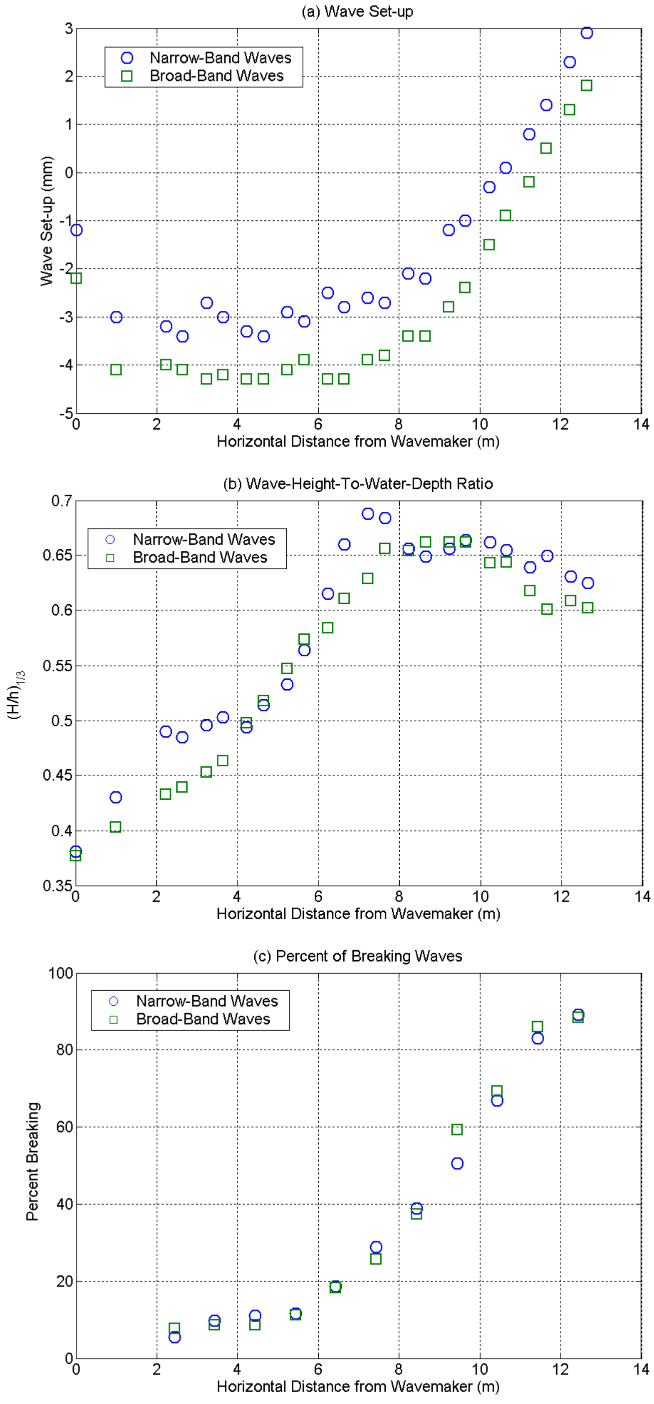

Figure 1. Variations of (a) wave set-up, (b) wave-height-to-water-depth ratio, and (c) percent of breaking waves with horizontal distance from the wavemaker for narrow-band and broad-band irregular waves.

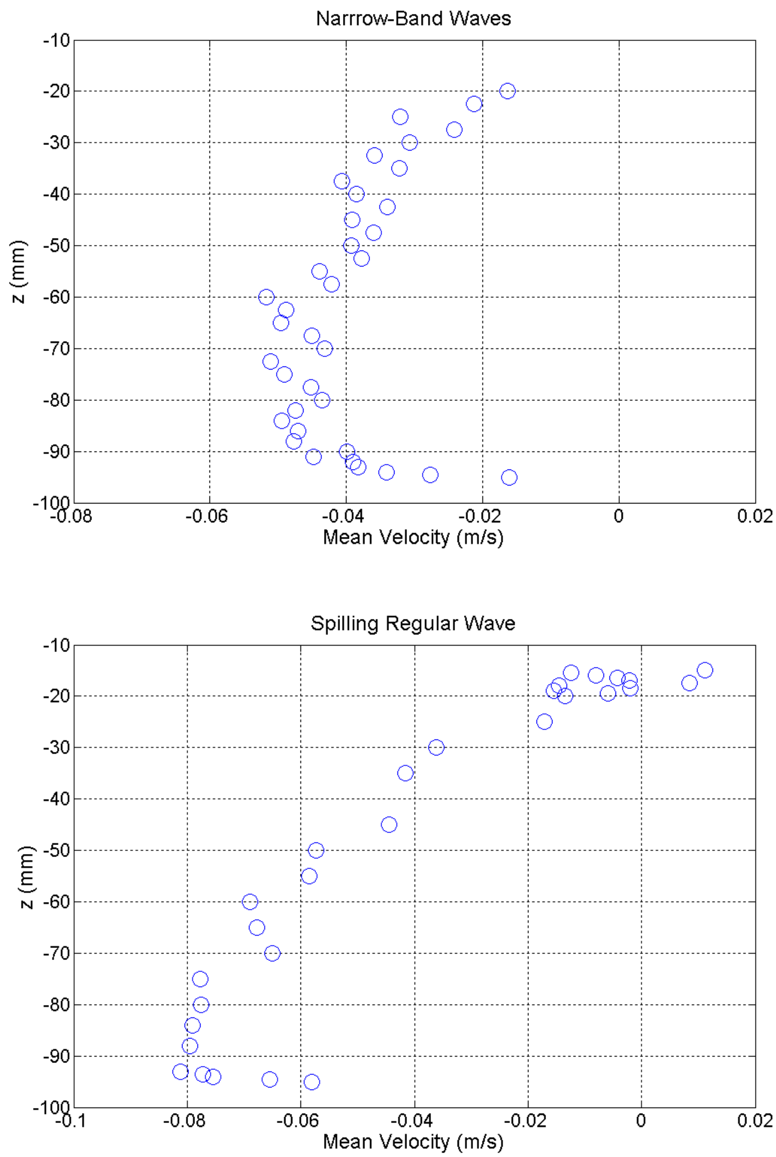

Figure 2. Comparison of measured undertow profiles from the inner surf zone for narrow-band irregular waves and a spilling regular wave. For the regular wave, the magnitude of the undertow increases with distance from the still water level with a very pronounced seaward current just outside the bottom boundary layer. For the irregular waves, the undertow profile is more uniform and lower in magnitude compared to the regular wave.